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Overview of the experimental tests in prototype

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Abstract. Experimental tests in prototype are necessary to understand the dynamic behaviour of the machine during different operating points. Hydraulic phenomena as well as its effect on the structure need to be studied in order to avoid instabilities during operation and to extend the life-time of the different components. For this purpose, a complete experimental study of a large Francis turbine prototype has been performed installing several sensors along the machine. Pressure sensors were installed in the penstock, spiral case, runner and draft tube, strain gauges were installed in the runner, vibration sensors were used in the stationary parts and different electrical and operational parameters were also measured. All these signals were acquired simultaneously for different operating points of the turbine.

1. Introduction

The dynamic behavior of Francis turbines is strongly dependent on their operating point [1]. There are certain points where instabilities could appear, affecting the hydraulic field, the structural parts but also the electrical output. Hydraulic resonances produced at part load [2] or full load [3] can affect the structure by oscillating the mechanical torque and resulting in oscillating output power, which in fact, is an important problem for the electrical grid stability.

The hydraulic field is usually studied in models in laboratory and its behavior could be transposed to the prototype with rather good agreement [3]. However, its application to the structure is not the same in models than in prototype since the structural characteristics are rather different. As a consequence, some dynamic problems that appear in prototypes cannot be studied in models and therefore they need to be addressed on-site. However, on-site measurements are usually difficult to be performed since the installation of sensors inside the machine needs time, preparation and availability and the economic cost is high.

In this paper an overview of experimental tests carried out in a large Francis turbine is presented. The turbine was selected for study under the European Project Hyperbole [4], where different companies, universities and research centers are involved. This turbine is located in British Columbia, Canada, and it has a rated power of 444 MW. The tests were performed during three weeks (November 7th to November 27th 2016), using the first two weeks for isolation, installation of sensors and deisolation of the machine, one day for testing and the last week for dismantling and removing the sensors.

2. Participants

Four different teams participated in the on-site measurements. A group of three people from Voith® participated installing strain gauges and pressure sensors in the runner, as well as a telemetry system to transfer the signals from the rotating to the stationary part. Two people from GE Renewable® installed pressure sensors in the penstock, spiral casing and draft tube. A group of three people from UPC



(Universitat Politècnica de Catalunya, Barcelona) installed vibration sensors in the stationary parts and coordinated all the measurements acquiring simultaneously all the sensors installed by the other partners. Finally, a group of three people from EPFL (École Polytechnique Fédérale de Lausanne) calibrated the wicket gate opening angle with the servomotor stroke signal in order to compare results obtained with the model.

3. Description of the equipment

3.1. General sketch of all sensors installed

Due to the big number of sensors and dimensions of the machine, a distributed measurement system was envisaged. The system from Bruel&Kjaer LAN XI Type 3053 was used for the tests. Figure 1 shows a sketch of the sensors installed in every location of the machine. Each group of signals was sent to acquisition modules Pulse (7 modules of 12 channels). From each module an Ethernet cable was routed to a switch and then to the main computer with the software for acquisition and synchronization of all modules. In that way the length of the cables and installation time was minimized. Sensors were located in the hydraulic system, on-board on the turbine (on the runner and on the shaft), on the stationary system (bearings and shaft) and in the electrical system.

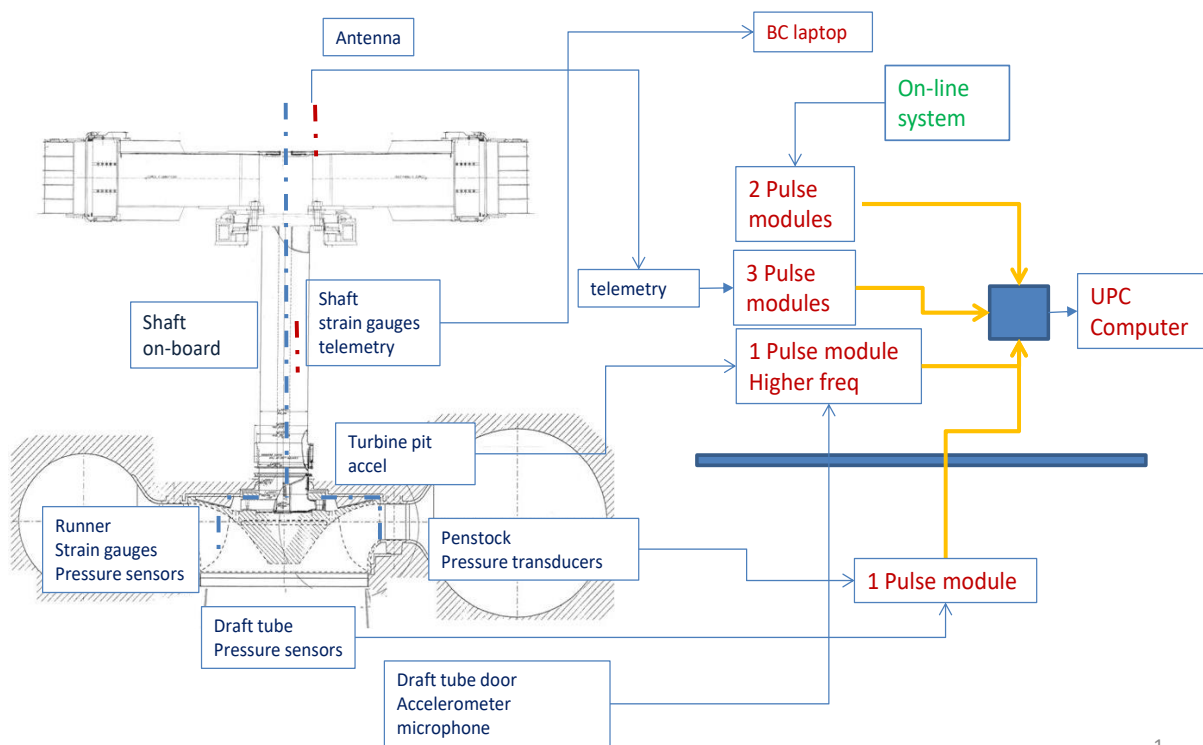


Figure 1. Sketch of the measurement equipment.

3.2. Runner instrumentation

24 strain gauges were located in two different blades of the runner. 8 pressure sensors were also installed in the same blades (Figure 2). The telemetry system was located in the cone of the runner and the rotating antenna was routed until the top of the shaft in the generator side. There, a stationary antenna was located and the signals were connected to the general acquisition system.



Figure 2. View of the cone of the runner where the telemetry system was installed and view of some strain gauges and pressure sensors located in the runner.

3.3. Penstock and spiral casing instrumentation

Pressure sensors were located in the penstock and spiral casing (see Figure 3).

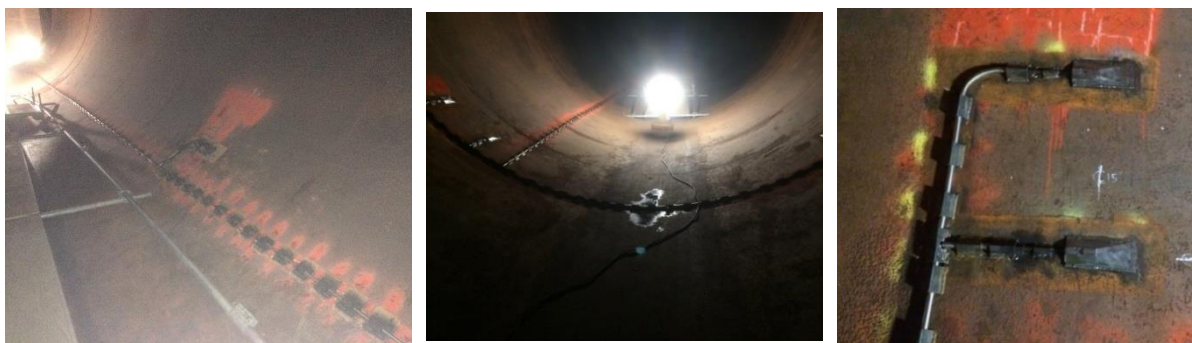


Figure 3: View of the pressure sensors installation in the penstock and spiral casing.

3.4. Draft tube instrumentation

Four pressure sensors have been installed in the draft tube cone (see Figure 4).



Figure 4. General view of the pressure sensors in the draft tube.

3.5. Torque measurement

For measuring the torque an on-board system with telemetry using strain gauges was installed on the shaft (see Figure 5).



Figure 5. Telemetry system installed on the shaft for torque measurement.

3.6. Vibration measurements

Several accelerometers were placed in the stationary parts of the machine: accelerometers in the bearings in radial and axial direction, on the head cover, on two different wicket gates, draft tube wall and casing. Moreover, four existing proximity probes (two in the turbine bearing and two in the generator bearing) were also used to measure shaft displacement.

3.7. Electrical measurements

Active power and voltage and intensity of one phase were also acquired at the same time than the other signals. These signals were taken from existing transducers in the power plant.

3.8. Operating signals

Rotational speed and wicket gate position were also taken from the existing Scada system and acquired simultaneously with the other signals. The upper and lower reservoir levels were also recorded during the tests.

4. Measurements

4.1. Measurements program

The tests followed the following sequence that can be observed in Figure 6. Several ramp-ups and ramp-downs, staying at different loads to identify the instability regions were carried out. Condenser mode and a load rejection were also tested. Operating conditions tested on a reduced scale model were reproduced in the prototype.

4.2. Overview of the results

As a first view, with the time signals of the different sensors, some instabilities can be observed. Figure 7 shows the time signals for different operating points. For a certain range of power, at part load, the fluctuation of the signals as well as the power is of relevant importance.

5. Conclusions

Experimental tests using several sensors on the rotating and stationary parts on a large Francis turbine prototype were successfully done. Pressure sensors were installed in the penstock, spiral case, runner and draft tube, strain gauges were installed in the runner, vibration sensors were used in the stationary parts and different electrical and operational parameters were also measured. All these signals were acquired simultaneously for different operating points of the turbine.

Hydraulic resonances and instabilities were identified for different operating points with different sensors. Further analysis is necessary to understand the phenomena.

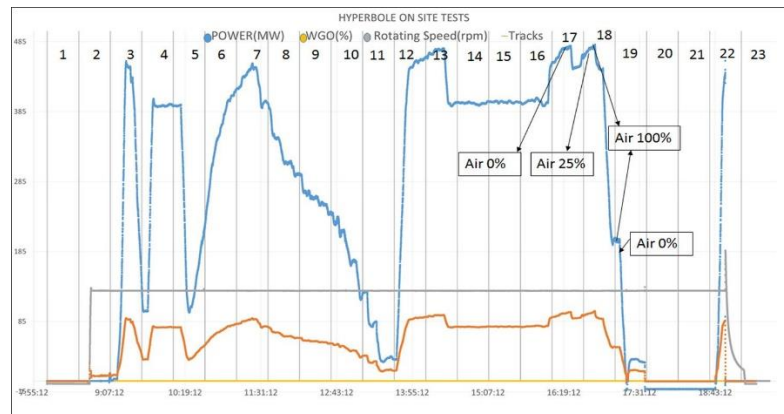


Figure 6. Evolution of power, wicket gate opening and runner rotating speed during the measurements.

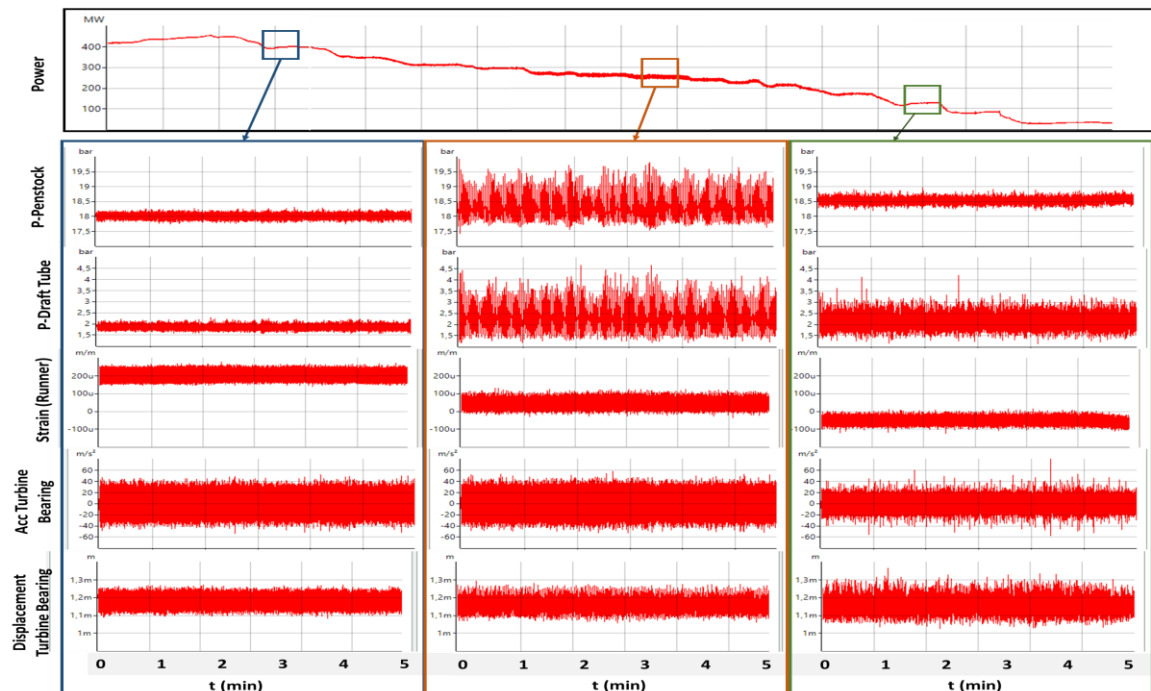


Figure 7. Time signals of different sensors for different operating points. From left to right, 400 MW, 260 MW and 180 MW.

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